Modeling of curved stiffened panels using refined 2D finite elements

Abstract.

Curved, stiffened panels are key load-bearing components in aerospace and marine structures, where weight, manufacturability, and stability place competing demands on the structural model. Accurate prediction of displacements, stresses, especially near skin–stiffener junctions, and buckling response typically forces a trade-off between fidelity and cost across the standard choices of full 3D solids, 2D plates/shells, or ad-hoc 2D+1D couplings. This work presents a unified, two-dimensional finite-element strategy for the analysis of curved panels reinforced by both straight and curvilinear stiffeners, developed within the Carrera Unified Formulation (CUF) [1]. In the proposed approach, the skin and each stiffener are modeled using the same 2D element; the stiffener height is represented along the element "thickness" direction and expanded by higher-order Lagrange polynomials, which both enrich the local kinematics and enforce skin–stiffener continuity at the Lagrange points without auxiliary constraints or tie interfaces. This CUF-based construction yields element matrices from compact "fundamental nuclei" that are independent of the selected thickness expansion, enabling systematic refinement when local three-dimensional stress evaluation is required at bends, corners, and junctions.

The formulation naturally accommodates geometric curvature in the panel midsurface and in the stiffener layout, so that straight stringers, curvilinear reinforcements, and mixed patterns can be analyzed in a single framework. Compared with traditional alternatives, i.e. 3D solids and 2D+1D beam/plate assemblies, the present 2D-only model delivers 3D-like accuracy in both displacement and stress while reducing degrees of freedom by an order consistent with plate kinematics, thus offering substantial computational savings for parameter studies and design loops. Across several cases, the CUF model reproduces reference 3D and high-fidelity literature results for transverse deflection, axial and shear stress components at critical points, and classical nondimensional buckling parameters, while capturing stiffener-dominated modes that require refined through-the-thickness kinematics.

Methodologically, the displacement field is expanded through the thickness with Lagrange polynomials of selectable order, combined with bi-quadratic in-plane interpolation, so that any desired level of through-thickness refinement can be introduced without altering the element architecture. This permits consistent stress recovery including transverse shear and normal stresses over the stiffener height and across the skin–stiffener corner, a capability that is typically inaccessible to classical 2D models and costly with 3D meshes constrained by aspect-ratio limits. In representative studies, the proposed elements match 3D reference solutions for displacement and stress with far fewer unknowns.

References

[1] Carrera, E., Cinefra, M., Petrolo, M., Zappino, E.: Finite Element Analysis of Structures Through Unified Formulation. Wiley, Amsterdam (2014)